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until the dot is again stationary during a revolution. Thus, by the first adjustment, the dot is in the axis of motion of the centre of the instrument, and by the second the same is made in the axis of motion of the dividing engine. For other instruments there are four adjustable dots placed at a convenient distance from the centre, and these are made to pass a wire in the microscope while revolving on its own centre likewise, when on the engine. This affords a great convenience in circular instruments, and is an improvement of considerable importance in sextants.

No. XIV.

IMPROVEMENT IN THE MICROSCOPE.

The LARGE SILVER MEDAL *was presented to Mr.* CORNELIUS VARLEY, 1, *Charles Street, Clarendon Square, for his Microscope peculiarly adapted for the examination of live aquatic objects, and his Apparatus for catching and retaining them.*

VERY early in life I was employed in making microscopes, and the lenses for them: these I always polished on bees'-wax, hardened either by Tripoli or red oxide of iron, a composition greatly superior to cloth, which still continues to be generally employed for that purpose; and, notwithstanding the advantages of using bees'-wax have been freely communicated to opticians, it has not yet got into common use in the process of polishing lenses.

On this account, and the defective adaptation of most microscopes for particular purposes, I again made one for myself, believing I could fit it much better than those hitherto in use, for viewing living objects with the very highest powers. The result is this microscope, for which the Society have favoured me by their approbation.

I will, first, state the advantages I have endeavoured to obtain by its peculiar construction.

2dly. Describe the instrument and its accompanying apparatus.

3dly. Shew how to improve or increase artificial light.

4thly. Shew the best means of reducing solar light to brilliant daylight.

5thly. Endeavour to shew the advantages of bringing the eye close to the lens, and the change of figure or position that should be made in particular cases.

And then describe the process of polishing lenses.

Having made the requisite lenses, my first care was to mount them so that the eye could come close to their upper sides, by which we obtain the widest distinct field of view, and yet keep the lens so clear below that it would freely approach the object.

The next was to provide a free movement for the stage, that may be used in any direction as quickly as the animalculæ themselves move.

And then to confine the animalculæ in the smallest range consistent with their preservation, and enable the deepest power to approach them.

A lens being requisite to bring the light in a condensed state to the object, it became of consequence to ascertain the best angle under which the light could be brought, and then perfectly to cut off or intercept all the rays that were not illuminating the object, and all that would not come within the given angle, and substitute for them the purest shadow or darkness quite close to the light that was in use.

I have therefore surrounded the cone of light with a variable dark chamber.

I have also adapted glass tubes to be used in a particular manner to catch the animalculæ and place them in the cages.

Reference to the Engraving, Plate IV.

The microscope, and most of its parts, are drawn half the real size.

Fig. 1, a side view of the microscope complete; it is made to clamp on the edge of a table.

Fig. 2, a front view, without the clamp.

Fig. 3, a top view of the stage; fig. 4 an under view, and fig. 5 a section.

Fig. 1, *a a* the cylindrical stem: it passes through the socket *b* of the stage *c c; d* the binding screw, by loosening which the stage may be quickly moved to the required place. The main or fixed stage *c c* is made uniform in thickness, and very flat on both sides, to allow the movable stage *e e,* which is also made very flat, to slide nicely on it, and to let the springing ring *f f,* fig. 4, slide as well under it.

The movable plate *e e,* the main stage *c,* and the thin ring *f f,* are kept together by three screws *g g g;* they pass through the thin ring *f,* the stage *c,* and then screw into the upper or movable plate *e,* see figs. 1 and 4, in order to allow of the requisite lateral motion of the plate *e* through a range of about four-tenths of an inch. The holes *g* in the stage *c,* through which the screws pass, are enlarged to that extent, as shewn by dotted lines at *g g g* fig. 4 and in the section fig. 5. The ring *f* is bent in three places intermediate between the holes, so that the holes recede from the stage; the three screws have then to draw it nearly flat, by which it springs so much against the stage as to cause a pleasant and easy friction whilst moving the plate *e*, and which holds it wherever it is put.

This free movement of the stage in any direction, is effected and governed by two parallel wire levers *h h*, (see figs. 1 and 2,) connected at bottom, so that one cannot move without the other. They pass through the descending ears *i i* of the stage *c*, which serves as a fulcrum, and then into the sliding plate *e*, to which they communicate motion from the hand of the observer placed on the connecting bar *j*.

This motion is of course as much slower than the hand, as the upper parts of the levers above the fulcrums *i i*, are shorter than the parts below them. The proportion I have adopted is one-tenth: it appears a sufficient reduction of the hand's motion for most of the high powers.

The bottom of each of the levers *h h* is bent into a small ring, which is placed between the two plates that form the connecting bar *j*; the screws which bind the plates together pass through the rings, and hold the plates so close on them as to prevent any shake, the levers *h h*, therefore, cannot incline different ways between the plates; they likewise move parallel in the cross direction, and cannot receive a twisting motion; thus they act as one piece in all directions, and move the stage correctly, as required.

The tops of the levers enter the two front corners of the stage above the fulcrums *i i*, therefore the stage moves parallel in a reverse direction to the hand; so, in whatever direction any particular animalcule may move, moving the hand the same way, apparently after it, brings it back. Thus it is quite a free motion, obvious at once to any one.

There are two spare ears like *i i* at the back of the stage, so that the wires *h h* may be placed at cross corners: the centre of the sliding surfaces is then correctly between them. In this case there is no bias to move otherwise than parallel; but when placed in front, as shewn in figs. 1 and 2, the hand scarcely feels the difference.

The magnifying powers that need this reduced motion view so small a space at a time, that an area of three or four-tenths of an inch is ample room to contain the objects. The motion of the stage is therefore limited to four-tenths by the screws which pass through the holes *g g g*, for the stage can only move through the space to which these holes are enlarged beyond the screws' thickness.

The movable plate *e* is seldom used as a stage. It is made large enough to receive the attachments and the apparatus for moving, and then a clear stage is raised upon it no larger than necessary. Thus the main stage is kept at such a convenient distance from the face, as to allow the fingers to rest on it while moving or operating on the objects which are on the upper and smaller stage. But in order to clear the lower stage *e*, when occasion requires, the neck which receives the upper stage screws into it, as shewn in the section fig. 5: on this neck is fitted the thin and springing tube or neck *k* of the stage *l*; this, by the upper stage sliding on or off it, may be changed for a large one to suit any particular object, and affords the convenience of being turned round to any position.

The springs *m m* for holding objects on the stage are shewn separate in fig. 6: they are united by the bar *n*: the under parts *o o* may fit into dovetail slides under the stage. Single springs or clips are also useful to apply to any part of the stage. It is likewise desirable to have pipes in the stage to receive the usual springs, that will hold any thickness under them. A pipe *p* is attached to the under side of the bottom stage, to receive the wire of the illuminating lens fig. 7: this figure is four times less than its real size. The mirror is flat and slides up or down on the pillar *a*; the condensed light is turned up by it to pass through the double stage, where it is purposely surrounded by the shadow between them, as will be seen in the section fig. 5. This shadow requires varying to the object, and careful adjustment to suit the power. For low powers, it may be improved by screwing in a blackened tube underneath the stage, merely to increase its length downwards, for the longer it is the more does it obstruct oblique light; and a black screen, like fig. 9, may stand on the lower stage, and be as high as the eye or face of the observer will allow, to exclude all light from above; or a black ring, like fig. 10, may be placed around the object: either of these improves the view of transparent objects.

But when using high powers, it is requisite to screw in a tube like *r*, fig. 5, to reach as near as possible to the upper stage without touching it. This tube, which is to form a dark chamber, projects below the stage with a sliding tube within it, to alter its length as occasion may require. The upper and lower apertures are to be lessened as the power increases; the upper aperture to be no larger than can be viewed through the lens, and the lower one lessened till it begins to diminish the light: then distinct vision will be obtained. The top view, fig. 3, shews the upper aperture as lessened for a high power. The inside of this dark chamber, its top, and the upper stage *l*, should be made black, with no tendency to shine.

The next care is mounting the lenses. In figs. 1, 2, and 11, *s* is a dovetailed groove on a pin which fits into the inner tube of the pillar *a*; it is sloped to an angle of 20°, to clear the cheek and allow the eye easy access to the lens. The disk *t*, figs. 2 and 40, is attached in the most compact manner to the dovetailed slide *u*, fig. 40, and is hollowed just as much as the eye can dip into, and still approach close to the aperture, and no more, because the aperture must not be removed away from the eye, nor be deeper than the eye can reach. This upper disk *t* is turned truly spherical, to fit the lower spherical and revolving disk *v*, in which are set the first five lenses, beginning at the lowest power — one inch, a half-inch, one-quarter, one-tenth, and one-twentieth. This forms a very compact arrangement, the spherical form of the circular mounting *v* always bringing the lens in use nearest the stage, and raising the others up above it quite out of the way; it therefore gives a clear view of the stage, and allows easier access to it: it also gives room for condensed light to shine on an opaque object.

The upper disk *t*, fig. 2, is turned with a thin edge extending to the dotted lines above it, that it may cover the upper side of all the lenses, and the spare sides are filed away, as shewn in the figure, to let the eye come close down to the aperture. The dished or spherical circle *v* revolves on a screw, which passes through its centre into the upper disk or eye-piece *t*: it also has five notches on the circumference, into one of which a light spring *w* always catches, when a lens is under the aperture in *t*.

The fitting by a pin under the dovetailed groove *s*, allows the whole eye-piece to be removed for substituting another, or allows it to be turned aside while placing objects on the stage.

It is best to give each of the higher powers a separate mounting, to enable us to remove every particle of spare matter from between the eye and object. Figs. 12, 13, and 14, shew the upper side, a section, and under-side, of such a mounting. The small disk which keeps the lenses in (shewn in figs. 13 and 14) may be retained by the finest screws, or by cement: the notch at one side is to introduce a steel point to lift it out when needful. The aperture in this disk should be a little more than flush with the lens, to protect it from being scratched, and it should be chamfered or made conical, to remove its corners, that a cork or soft wooden point may enter to wipe the lens all over.

The quick motion is given by loosening the screw *d*, fig. 1, and raising or lowering the stage; but the slow motion is from the screw *x* at bottom of the pillar *a*, which raises or lowers the eye-piece.

For this purpose, the tube which receives the pin of the eye-piece at top is made to slide within the pillar *a*, as shewn in the section fig. 11; and it is entered at bottom by the adjusting screw with a milled head *x*. There are two faults attendant on this screw, both of which will increase, unless counteracted; one is wearing loose at the shoulder which confines it to the bottom, the other is a wearing of the threads of the solid and hollow screw: each of these causes a loss of motion, by permitting the screw to turn a little without moving the sliding tube. I will therefore describe the means of curing these defects: To remove all end-shake that would occur from the shoulder wearing, a short spiral or other spring is placed on the milled nut x, to act between it and the seat on which the screw-shoulder rests; this keeps the screw always down on the seat, and thus prevents end-shake, whether the screw is turned one way or the other. The other fault, which is occasioned by the screw wearing loose in its hole, thereby enabling it to make a portion of a turn, without pushing or pulling the tube, is sometimes coarsely cured by splitting the screw-hole, and making the two halves spring towards each other, so as to pinch the screw between them. A better mode than this is shewn in fig. 15 : on the screw x is placed a separate screwed nut, a little way below the bottom of the sliding tube, and two pins or screws pass through it into the tube, merely to prevent its turning round. This nut is to be urged from the tube by interposing a spiral or other sort of spring between them : this arrangement will keep the tube always pressing upwards against the screw-threads.

But as a weight or pressure from above on the eye-piece could overcome these springs, and such an accident, with high powers, would endanger their being pressed on an object to their mutual damage, it is therefore best, in the first instance, to confine the tube downwards, at its lowest possible place between the threads of the screw, so as to press on them. This is done by using a similar nut on the screw, a little separated from the tube, and urging both towards each other by springs, outside or under the nut, as in fig. 16. These springs are made to act against the nut by the small screws which pass through them and the nut into the tube, and also keep the nut from turning round with the screw. With small tubes, several such springs must be put together to give sufficient springing action; but when the outer tube is large enough to give room, a single steel nut, with a very thin flanch, filed so as to leave three springing arms, as shewn under fig. 16, will do: three small screws pass through these arms into the tube, and at once keep the nut from turning round, and, by drawing the springing arms towards the tube, pinch the threads of the adjusting screw that are between them, so as totally to prevent end-shake. Thus let the screw fit ever so loosely, the tube and it are kept together just as if they fitted quite tight; therefore, when the adjusting screw is fitted with the two springs, as in figs. 11 and 16, the eye-piece perfectly obeys the very smallest motion given to the adjusting screw by its milled head *x*. This latter may be a micrometer head, to measure the real thickness of transparent objects. Having thus obtained a perfect adjustment, it is of consequence to remove all lateral motion of the lens over the object, which is liable to arise from the inner tube having a tendency to be twisted or turned round the way the adjusting screw moves: this fault, when using high powers, is liable to carry the object quite out of the field. My late uncle, above thirty years ago, introduced the triangular bar and triangular tube, they affording an excellent steady motion that was not affected by the adjusting screw; but it requires good workmanship to make the slides fit perfectly well on them, or when the bar slides, not only to make it perfectly fit the triangular holes, but also to make these two holes perfectly coincide; for if there is the least disagreement, the tube cannot lie close in to the angles of both; but whilst it coincides with one it will tilt in the other, and it would then rock to and fro with the alternations of the adjusting screw. The triangular bar fixes the direction of the stage and mirror, or whatever slides on it; but this did not suit my purpose, as I wished to be able to turn any or all the parts round on the pillar *a*. I therefore chose round tubes, and adopted the means shewn in figs. 11, 17, and 18, which totally prevent the inner tube from twisting or turning in the outer tube or pillar *a*, whilst being raised or lowered by the adjusting screw *x*.

For this purpose two long and very equal slits *y y*, fig. 11, are made in the pillar *a*, exactly opposite each other: in these move two parallel slides *z z*, which are screwed to the inner tube, each having a spring screwed close to its side, so as to act against one side of the slit. These springs always urge the pieces *z z* against the opposite sides of the slits, thereby overruling all tendency of the adjusting screw *x* to turn the inner tube round when it alternates. This vertical motion is quite as good as the triangular bar, and I prefer it, because in a small-sized pillar there is more room for the internal work.

In order to give the hand free access to the adjusting screw *x*, and to be able to attach to it a divided plate for a micrometer head, and also to give room for the hand that holds the bar *j* whilst moving the stage laterally, the base of the microscope is removed to one side by the cylindrical bar or tube 1 1, fig. 2, which projects at right angles from the bottom of the pillar *a*; it passes through the short pipe 2, and the microscope may be held in any position by the binding screw 3, fig. 1. The lower or side pillar 4 4 is conical at bottom, with a channel 5 round it: it fits tight into a conical hole in the clamp, fig. 1; and when this clamp is fixed to a table, the microscope may be turned about to any light: the point of the screw 6, at top of the clamp, may be advanced into the channel 5, to prevent the microscope being plucked out. The side pillar 4 may be in two parts, to allow one to slide within the other, and afford the convenience of varying the height.

The tweezers are shewn in fig. 19, with a compound joint; they are to be attached to the stage *e* by the screw 7: the forked spring 8 grasps a channel round the screw 7, and has a restraining screw 9, which merely prevents it rising enough to let the screw 7 fall out from its place. The screw 7 fits any of the holes 10 on the stage *e*, fig. 3, and is screwed tight enough to bring down the spring 8 from touching the screw-head 9. The spring 8 then causes its bar or arm to rub with a pleasant and easy friction against the stage while being moved, and holds it stiff in any position. The forked spring 11 acts in a similar manner on the joint 12. Figs. 20 and 21 shew a pair of tweezers, jointed to another socket *b*, to fit on the pillar *a* when the stage is removed. This socket springs enough to hold itself, but has a binding screw *d* to fix it.

Fig. 22 shews a spring and part of a joint separate. One or two small sockets 13, figs. 20 and 21, may be fixed to the socket *b*, to receive the wire of an illuminating lens, or a black disk to serve for a dark back-ground to an illuminated object held in the tweezers.

Having limited the stage motion to three or four-tenths of an inch, it becomes requisite to confine the animalculæ to a space of that diameter, and also to a very limited thickness, in order to keep them within reach, and as near as may be within focus of the highest powers.

For this purpose I have mounted a small glass tablet 14, figs. 23 and 24, which are sections of the same, and fig. 25 is a top view. It is made of a piece of well-polished plate glass, cemented on a small chuck, and ground conical at the grindstone, then put to the lathe and turned with a diamond, keeping it wet all the time by a sponge or cloth supported at the opposite side so as just to touch it; the upper part is turned cylindrical, and the base allowed to spread out for the purpose of being held in the mounting: it is then cemented or burnished into the neck of the disk 15, which is hollowed so as to leave a clear space all round the tablet. The aperture under the tablet is of the same diameter as the top; more or less is injurious: the outside of the neck is turned with a fine and true screw to receive the screw-cap 16, which has an aperture through its top one-eighth of an inch larger than the tablet, to remove all matter from around it. Above this aperture is a flat recess, as large as the cap will allow, to receive a circular disk of talc 17, which is to be cemented in: the rim round the talc is essential to protect it from the fingers when screwing the cap on or off, but it should be only flush with the talc. The seat should be moderately broad and very flat, that it may hold the talc quite flat. The sides of and recess around the tablet, and the whole top of the disk, should be blackened. The drop of water containing the animalculæ is put on the tablet, and the talc cap screwed on till it touches the drop and spreads it out as wide as the tablet, and no more; this renders it flat, and when put on the stage the objects it contains may be viewed with great ease and convenience. I call these *capillary tablets*, or cages, several of which should accompany the microscope; for the fluid and animalculæ are retained at the top of the tablet only by capillary attraction, and will bear turning about any how, without leaving the top, provided it be not suddenly shaken.

In addition to these, I have constructed fishing tubes for catching the animalculæ we wish to observe, and placing them on the tablets with the greatest ease from a vial or large jar.

Having with an eye-glass observed where the objects are most numerous, I introduce the glass tube, fig. 26, closed at top with a wet finger: this prevents the water getting in; and when its point is near the cluster or the particular object I wish to catch, I suddenly take my finger off, and immediately afterwards put it on again, and quickly lift the tube out of the water; it will now be almost sure to contain what was near the tube at the time. If, as is frequently the case, the tube contains more water than can be allowed, I drop it in a watch-glass, fig. 27, which spreads it, and again catch the object by putting quickly the tube 18 over it; capillary attraction draws it in with less water, which may be put on the tablet; but if there is still too much water, I touch the tablet to draw some out; and if the object is not there I wipe it off, and repeat till it is there, with only enough water. Again, when I wish to place several individuals together on the tablet, it is requisite to take each up with very little water. I then empty the tube on a slip of glass, fig. 28, in separate drops, and with a capillary tube but little larger than enough to catch them, lift them out one by one, and place them on the tablet.

Some sorts are kept alive much longer by having vegetable matter added. Fig. 29 shews a pair of long and very narrow *sharp-pointed* tweezers: they require a hole and steady pin at 19, to keep the points accurately together, and the points are bent to one side: they serve very conveniently to put into a vial, and take out a small portion of any vegetable matter: this is sometimes ready crowded with animalculæ, otherwise I take up a little conferva (hair-weed), and cut a portion shorter than the tablet's width, and spread it in a watch-glass full of water, and again take up just enough to add to the tablet: some of the animalculæ will be found to have fixed themselves to it; and those that are very quick in their motions are greatly interrupted by it, and are therefore better viewed. Figs. 30 and 31 are two other tubes, to be used as fig. 26. Fig. 32 is a dark screen, very useful to stand before the microscope, and shade the table below by intercepting all the rays but those about the mirror: it may have a perforation or sliding arm, so placed as to intercept the rays quite close to those which you perceive you are using by its beginning to darken the field. This sensibly aids the dark chamber already surrounding the light under the stage, by darkening those parts of the object which, though in view, are not wanted, and sometimes parts of the field which have no object to obstruct the pure light from passing to the eye.

There is one more accompaniment to be described,—a cell for small aquatic plants, shewn in fig. 26, Plate V. It is made with two slips of the thinnest glass, or one of glass and one of talc; they have three very narrow slips of glass interposed between them at the ends *o* and *p*, and along the bottom *q*, where they are cemented together so as to form a water-tight vessel. The off slip is wider than the near one by the portion *r r*: the vessel being filled with water, this extra portion serves to lay the plant on and let it gently slide in; if not used vertically, it must be inclined upwards enough to keep the water in.

When by a lens whose focus can reach through this vessel, I discover a part requiring a higher power, I introduce either a slip of talc or glass, made smooth at the edges, to occupy the space beyond it, and thus confine that portion to the near side.

I have now described the microscope, with its apparatus, and the method of charging the cells and capillary tablets; and, having already described the means of obtaining shadows, I will now endeavour to shew how to determine the best angle for the cone of light that is to illuminate any particular transparent object, and how to lessen the angle without much lessening the intensity.

If we take a small vial full of water, or a glass rod, and hold it close to the middle of a window, we shall see light through every part, and therefore are not conscious of the strong refraction that is taking place, so we lose the power of knowing what it is, whether full or empty, flat or round, denser or rarer; but if it is gradually withdrawn from the window, the edges will soon begin to appear dark, and these shadows will keep widening or closing in towards the middle as it is withdrawn, till the light is reduced to a very narrow line. Thus at both extremes we lose the power of knowing the objects; in one case it is a line or parallel bar of light, not distinguishable, or scarcely so, from the surrounding light; in the other, it appears a dark line, or two parallel dark lines close together: therefore a medium distance, where the window subtends an angle of about 30°, is the best for viewing such an object, for then the light and shade in the cylinder are nearly equal to each other. In this case the apertures of my dark chamber should be such as would let a cone of 30° pass them.

A cylinder, when viewed before a narrow angle of light, reduces that light to a very narrow line, which makes the cylinder appear to be split in two; and when the cylinders are so small as to appear but lines themselves, the narrow lines of light down their middle are too small to be seen, therefore we are apt to conclude that these cylinders are opaque, but a wide angle of light being brought to them will shew their transparency. Thus all opaque portions should be examined by a wide angle; and for other parts the narrow angle should be resumed, as that always gives the sharpest and most distinct vision. If the cylinders we have been viewing are dry ones, we may, instead of widening the angle of light, immerse them in water, or any fluid that will considerably lessen, but not totally remove, their refractive power, and their transparency will appear, agreeably to the experiment now to be related.

Take a wide or a flat-sided glass vessel full of water, and immerse part of the glass rod in it; the refractive power will now be so much lessened as to require double the distance from the window to equalise the light and shade; therefore a cone of light of 15° will define it best. Next, immerse the filled vial in water, and it will disappear, excepting the thin glass film, having lost all power of refraction. This film requires a very narrow pencil of light, and must be brought close to the side of the light, and nearly touching the shadow, to become visible: there are animalculæ whose skin or envelope is only visible in this way. But, disregarding the glass film, dissolve some salt in the vial, to give it a very little refractive power, and it will remain invisible till the angle of light is reduced, by distance or otherwise, nearly to parallelism, and then it will appear or become visible by its refraction, bringing the side shadows to the eye.

Thus different objects, and different parts of the same object, require different angles of light to render them equally visible; therefore we must examine the same specimen under different angles, before we can judge correctly what they are. These experiments may be varied, to shew how requisite it is to vary the angle of light, and keep it closed round with total darkness. If at a distance from the window or light we hold a lump of salt at the surface of a glass of water, the solution, while falling down, will be distinctly seen by its refractive power; but take it close to, or hold it out of a window, in a wide angle of light, and the solution, though falling, will be invisible; but move it towards the dark side of the window, and it will begin to appear as soon as the shadow comes within its small angle of refraction. Some of the most difficult parts of animalculæ and plants, namely, those that are quite transparent, can only be rendered visible by the same means that render the falling solution visible.

We may form a judgment of the figure of an unknown object when viewed under a given angle of light, by viewing known objects under the same angle, or by imitating the supposed figure, and viewing this imitation under the same circumstances of light as the real object. Thus, in order to judge whether the spiral vessels of plants are solid or tubular, we may coil a small glass thread and a small glass tube into the form of a spiral vessel, and view them in fluids of different densities; or we may attach to each of them a film of isinglass, or a drop of a solution of soap; then, if the thread or the tube resemble most the spiral vessel, we may conclude that it is solid or hollow, according to such resemblance.

The above experiments will shew, that to make ourselves well acquainted with an object we ought to view it under different angles of light, but that a long cone or medium angle is generally the best; and this can be had with the solar light as intense as the object will bear. But with artificial light, care is requisite while we are lessening the angle to preserve the intensity, When a wide angle is wanted, a double convex lens with a large aperture may be used, placing the light four times the solar focus from the object, and the lens exactly half way between them; for a narrow angle, a plano-convex, with its flat side to the light, or one crossed as *a*, fig. 1, Plate V. suppose one to five, is best: place the light in one focus, so as to give the other focus, where the object is to be placed, five times as far off. When the lens is placed in this way, it takes the widest angle of rays from the light, and conveys them condensed under a narrow angle to the object. When it is required to bring the rays parallel, or nearly so, a concave lens *b* may be placed under the dark chamber *c c*, to conduct them through at the reduced angle, with all the condensation we can obtain. With this parallel light the smallest differences of refractive power in the object will render it visible, by finding shadow near enough to bring to the eye.

I will now describe two improvements in the light itself, which appears to have been much neglected. If several candles are placed in a row, one behind the other, and the glare reduced by looking at them through a dark blueish green glass, it will be seen that the flames are transparent, they being distinctly seen through each other; therefore a single light is very poor, and yet observers appear to have been content with it. If we keep adding more flames till we cannot discover any increase of light, we shall approach the maximum density; then, if we look at this body of light through a glass so dark as very nearly to obscure a single light, the difference will shew the great increase of light obtained by using such a compound flame. To ascertain the number of flames that are requisite to become quite opaque, (in which case we arrive at the maximum, and obtain the fullest possible body of light,) it is requisite to have two such rows of lights placed end-ways to the eye, so as to appear like two single flames; then, looking at them through the very dark glass mentioned above, slide one row behind, or in continuation of the other; if the second row can be seen through the first, or be seen to increase the light, it will shew that they are wanted to increase the body; but if not, we may be satisfied with the first row. Very thick flames have a dirty opacity, from the imperfect combustion within, therefore one great flame will not do; we must use a number of flames, so thin that each may have complete combustion, to obtain the best effect.

The next improvement in the light consists in the mutual action of flames on each other. If two flames are placed so near to each other as almost to touch, that is, let their small faint atmospheres touch, the light will immediately equal three separate flames; therefore we should place all the flames of our compound light so as just to touch in this manner, taking care to leave room for a free access of air from below to rise between them.

Suppose six flames are used, this contact would make them equal to nine. In Plate V. fig. 1, is a side view, and figs. 2, 3, and 4, are top views, shewing different modes of arranging several flames or burners to effect this purpose. Those portions of flame that are out of the cones *d* and *e* send no rays to the microscope, but all that are within them do, if their number is not more than enough to produce a full body of light.

After all our efforts to improve artificial light for microscopes, there is none quite equal to daylight in its quality or fitness for giving distinct vision. But when applying high powers to objects whose thickness or colour lessen their transparency, we are compelled to use stronger light. But as daylight, or, as concerns the microscope, more properly clouded light, is indirect solar light, it is desirable to understand what causes so great a difference as to make cloud-light the best, in order that we may be able, after strongly condensing the sun's light by artificial means, to produce the same effect or change of quality in such light as a cloud does in nature.

When we view with a high power any transparent object, we see its parts from their refractive power bringing lights or shadows accordingly as they are circumstanced, and with little or no prismatic colour; but the solar light on the same object appears to reduce it to a mass of brilliant prismatic particles, and the appearance is nearly the same when adjusted either within or without the focus; therefore when adjusted to what we judge the best vision, it will frequently be found, on bringing cloud-light instead of the solar, that the object is out of focus; hence it frequently happens, that when employing solar light we are only viewing irregular forms produced by refraction instead of the real object.

The sun's light comes to us with all the colours combined in one right line in each ray; when this passes through an object, refraction takes place, and the light is divided into the several colours, which dazzle the eye and confuse or even destroy vision; for it sometimes happens that this dispersion is so great as to leave few or no rays to co-operate and bring the real forms of objects to the eye. But, if the solar light falls on a cloud before it reaches us, it is there completely decomposed into all the colours, and if it falls on a mass of snow the same effect is produced ; for snow, under a magnifier, is seen to be minute angular crystals, each of which is prismatic; consequently the whole is a mass of prisms, which decompose the sun's rays into all the colours; and the reason we can see no colour is owing to the decompositions of each part mixing with the decompositions of its neighbouring parts; it therefore produces a neutral flatness, deadness, or perfect uniformity of whiteness, or colourless light. When this neutral decomposed light passes through an object, it appears incapable of farther decomposition; we therefore obtain undisturbed vision, approaching the character of monochromatic light.

For reducing the solar light which is condensed at the focus of a large lens, to this neutral or daylight character, and preserving its brilliancy, I have tried *finely-pounded glass, carbonate of soda,* a broken fragment of *white marble,* and also *chalk.* These were alternately laid on the mirror, which was placed flat so as to hold them under the stage, where they received the focus of an eight-inch lens, three inches in diameter.

The chalk improved the light, but did not destroy all its prismatic colour; the marble was still better, giving a white light; but the *carbonate of soda,* or the *pounded glass,* appear decidedly superior, giving a very pure and brilliant daylight.

As this light cannot always be had close under the stage, a lens may be placed below the stage, the two foci of which will reach, from this bright artificial cloud, through the stage or dark chamber, to the object.

It requires a considerable thickness of pulverised glass, or a large lump of dried carbonate of soda, to form the brightest cloud; but if placed on the mirror, or in a bright tin box, half the thickness will do, because the light which passes through will then be returned by reflection, and increase the brightness, for the cloud is always larger than can be used, therefore it is best to return back the redundant portion.

Having now shewn how to obtain artificial light of the utmost purity and intensity, and how to reduce the most powerful solar light to neutrality, and to use it closely accompanied by complete shadow; also how both kinds of light may be governed so as to place the objects in the most favourable circumstance for being viewed, with constant equality of effect; it may be well to revert to the lenses, to shew what sort are best for particular purposes, and to shew what takes place when they are differently circumstanced. I have used this microscope only with single lenses, or doublets, but it is quite suitable for a compound body, provided it is made strong enough to bear the additional weight.

Achromatic object-glasses have been made by Mr. Wm. Tully, with very short foci, of such an admirable degree of perfection as to need nothing farther to be said of them by me, therefore single lenses are not likely to be again used for object-glasses; yet, as imperfections do more or less accompany all uncorrected lenses, I will first shew what takes place when we are using a lens for an object-glass to a compound microscope, because the evils found there, to a considerable extent, do also more or less accompany the use of all single lenses. In Plate IV. fig. 33, is a diagram to shew the advantage which a lens of short focus possesses over a long one, the magnifying power in both being the same: *a* is the lens with the longer focus, *b* an object, *c* its magnified image: here the rays of light from the object, as soon as they enter the first surface, begin to suffer injury by dividing into the primitive colours; and this splitting or decomposition of the rays will be twice as much if the lens is twice as thick, before their exit at the other surface; then, at their exit, there is a second increase of this division or decomposition: each ray, therefore, like the ray *d*, instead of arriving whole and entire at *e*, will be divided or separated, as shewn by the dotted lines *f* and *g*, into blue, yellow, and red rays. Thus the image is always ill defined, and will bear but little magnifying; for suppose the object be a moth's feather, possessing very fine and close lines, as soon as the burr which is found on one line is spread wide enough to meet that of the neighbouring line, we must stop magnifying, for if we increase the size of the image, in the hope of separating these lines, the burr will increase with it, and forbid any more defining; on the contrary, the defining power will be lessened, and what we obtain a glimpse of with a low power will be invisible with a high one. Thus, from this imperfection, we are limited to such magnifying power only as causes the burr to fill the space between the parts which we wish to see separate. Now, instead of the lens *a* let us use the smaller one *h*: here it will be seen that the whole of the same rays of light proceeding from the object *b* will have to pass through the lens *h*, and that exactly in the same manner, the angle in both cases being precisely the same; therefore not a particle of light is lost by using the small lens instead of the large one, and the same injury begins at the entrance of the rays; but this lens being only one quarter as thick as the other, the rays are opened or divided only one quarter as much at their place of exit; and on their exit the same additional opening or dispersion takes place. Therefore these rays might arrive at the point *e* with as much less error as was saved by the lens being thinner, and, consequently, will magnify four times as much before we are stopped by its indistinctness ; but if we receive the image at *i i* it will be magnified as much as in the first case, and with as much light, and it will appear four times as distinct, for the rays are dispersed only one quarter as much at *i* as they are at *f g*. There is another source of indistinctness, namely, the error from figure ; for the rays passing through the edge, are brought to a focus sooner than those which pass through the centre; and though this evil is lessened by reducing the aperture, we lose light in so doing, and thereby limit the power; but as the error by figure is four times less with two lenses, we obtain a larger apperture by using two. These lenses are likewise greatly improved if they are unequally curved, which is technically called crossed, that is, letting their under sides be as much flatter than the upper as the upper focus is longer than the lower. This dividing of the rays consequent on their passing any single lens, is an argument in favour of always receiving the rays as soon as possible after their refraction, and therefore to bring the eye as close as possible to the lens, that the rays may enter before their division becomes sensible. We will pursue this subject with single lenses. The error by figure of a lens is four times less if we halve its aperture ; therefore, a lens whose focus would enable it to bear a large aperture will perform best when reduced nearly to the size of the pupil of the eye, and made as thin as that aperture will bear. Fig. 34 shews a lens under the two cases of large and small aperture. Let *j j* be the small and thin lens, and *k* the pupil of the eye as near to it as possible; the eye will then view every part of the object through the middle, with but little lateral deviation, and the lens being comparatively flat, the difference of focus between the centre and edges is too little to be of consequence ; therefore, as every part nearly co-operates, it shews a wide field most distinctly. Next enlarge the lens to *l l*, and double its former aperture, which makes it four times as thick, increasing the error on that account and also by moving the eye farther off; but let the pupil be placed at *m*, where it uses the whole aperture to view the same object *b b*, and it will see the middle of the object through the centre nearly as well as before; but the circumference *l l* is four times worse in figure, and its focus is shorter than at the centre, therefore the medium focus of the ring *j j* will most naturally be adjusted to the object: thus, neither the centre nor circumference can give easy vision. When a large aperture is used, fig. 35 will shew why the eye feels easiest at the distance *o*. Notwithstanding the above fault, *m* is the centre of the dotted segment *n n* which represents the curve of the lens, and where the eye would be equidistant from each part, and only see the portion *b b;* but by lowering it to *o* all the parts of the lens are in the best position or angle in which they can be between the eye and the parts of the object viewed through them, for the rays come to and go from the lens at the same angle; therefore the portion *p p* is seen tolerably equal, and the aperture cuts off what could not be defined. But let the eye descend lower for the purpose of seeing more, the edges of the lens, which were previously bad, will become worse by the increased obliquity of the rays : hence any additional portion will be ill defined, and the want of a distinct boundary will render what is seen well near the centre unsatisfactory; yet the vision improves as the eye descends, provided the aperture lessens with it to cut off what is bad. These lenses are curved as one to six, and when made thin shew the largest possible field distinctly, and are, therefore, generally considered to be of the best form and position; and so they are, while extent of field is the aim, and while the lens can be placed nearer to the eye than to the object; but we shall see reason, as we increase the power, to pass even the double and equal convex, and use plano-convex lenses with their flat side downwards. The smaller the lens the larger in proportion is the aperture we are obliged to use: thus, when the aperture is of necessity much less than the pupil of the eye, we must give up some distinctness in order to increase the light, and we can no longer use comparatively thin and flat lenses, like *j j*, fig. 34; but we must allow, at least, the proportion of diameter *l l*. The focus of the circumference is shorter than that of the centre, and is rendered worse by its position lifting that edge farther from the object; therefore, when the middle is adjusted to distinct vision, the edges are too far off to act, but produce a fog, which confuses what is seen through the centre. I have thus shewn that large apertures are bad, yet with high powers we are of necessity compelled to use them. When using large lenses, without bringing the eye close, different portions about the diameter of the pupil are used for different parts of the object, as will be seen by fig. 35; but though the parts differ, the rays of the pencil from each part of the object do not differ so much among themselves, and vision is obtained.

In fig. 36 the lens is less than the pupil, therefore a pencil of rays equal to the whole aperture of the lens enters the eye from every part of the object. In this case, an equally convex lens is the best for extending the field, the inequality of angle at which the rays enter being partly corrected by their exit through the opposite curve;

still, a considerable portion of these rays is bad, and cannot be prevented from entering the eye, where they injure the perfect rays and lessen distinctness. Therefore, to obtain a correct or distinct view of the minute parts, we are obliged to give up extent of field, and so place or figure the lens as to make it render the largest angle of rays proceeding from one point parallel. This is effected by a plano-convex with the flat side downwards, as fig. 37: here the dotted line *n n*, which represents the curvature of the lens, is everywhere equidistant from the centre *q*: thus the foci of every part meet there, and give a very distinct view of that small part. The oblique view is here so bad, that altering the adjustment cannot make it distinct; therefore the eye is not obliged to come so near to the lens to obtain it; but, from what was shewn in fig. 33, of the prismatic dispersion, the eye should be placed as near as possible. The unity of focus in this sort of lens gives it a penetrating power; for everything disappears that is the least out of focus, leaving the part in view apparently detached. But if we wish to see a larger portion at once, in order to judge of the relative situation of parts of the object, the equally convex lens, fig. 38, will answer; because here there is a variety of focal distances between *r* and *s*, by which we are enabled to see farther and nearer than the point to which we adjust. This, though a merit here, is a fault in every other respect, for it is a cause of confused vision. The error by figure is four times less with two lenses, and nine times less with three; doublets or treblets are therefore used with great advantage to increase the defining power; and this they do greatly beyond any single lens. Yet what has been said about the position of single lenses applies to these. For high powers their flat sides are downwards.

In the doublet which Dr. Wollaston has adopted and applied to the microscope, the lower lens is smallest, and being separated some distance from the other, it approaches so near to the object as almost to touch it.

By carefully adjusting the curves, the foci, and distance of the two or three lenses for a doublet or a treblet, a much greater correction is obtained than by the mere number of glasses. It follows, that the hopes of perfection entertained by using a diamond lens, can only be realised by making a diamond doublet.

I still possess the first diamond that was ever formed into a lens. Its great expense consists in the great length of time it takes to bring it into figure, and also in the quantity of diamond-powder it requires to produce a polish on its surfaces. This diamond lens was worked conjointly by myself and pupil, at the particular request of Dr. C. R. Goring, to whom the credit is due both of suggesting and urging the attempt, and likewise of contributing towards the expense. It is but justice to record the fact, that the diamond lens, as well as the small achromatic object-glasses, so perfectly executed by Mr. W. Tully, of Islington, owe an earlier existence to the liberal zeal of Dr. Goring, to whom the scientific world is much indebted for the creation of such superior means for investigating the most minute objects of nature, both animated and inanimate. By comparing this diamond with a plate-glass lens which I made in the same tool, the magnifying power of the diamond proved to be nearly as eight to three of the glass. It should, however, in fairness be stated, that this is not all gain; for the diamond reflects so much more light from its surfaces than glass does, that much less is allowed to pass through it. This circumstance, therefore, brings a glass doublet much nearer on a par with a single diamond, if it does not really surpass it.

I expect more from Herschel's doublet than from Wollaston's, because the power is increased by the combination ; whereas, in Wollaston's the power is less than the deepest lens.

Herschel's is worthy of him, being calculated to give all the power that can be obtained by a correcting combination, the lenses being close together; therefore, if made as thin as their best apertures will allow, they leave the most room between the lens and focus.

Wollaston's is made with plano-convex lenses, which are a considerable distance apart, in order to be in the places where their errors balance or correct each other; but by this arrangement, a considerable portion of the space between the focus and its nearest lens is lost: therefore, if both are made as small as workmen can execute them, Wollaston's could but just be used through the thinnest talc, while Herschel's would have room, and be about twice the power.

Mr. Herschel has, in the *Philosophical Transactions*, given the four curves for his doublet, and they are given in Mr. Valentine's paper, immediately following. Each power requires four tools very accurately proportioned to each other: it is, therefore, to be feared, that they will be executed accurately only by workmen who are zealous in the cause of science. Whereas, Wollaston's requiring but two tools for each power, one of which may always suit another power, and one flat tool being common to all the lenses, will satisfactorily account for their coming into the market first.

Several years ago I made one of Herschel's doublets, the sixth of an inch focus, at the particular request of Dr.

Goring, whose zeal for the microscope made him desire to verify the calculation; and its performance justifies the above comparison.

The magnifying power of a single lens is determined by comparing the distance of an object from it when seen most distinctly, with the nearest distance we can easily see without it. But this distance varies in different persons, and gradually increases from youth to age. Very young persons can generally see at four inches from their eyes, whilst the aged require ten or more inches distance to see distinctly: therefore, to the young an inch lens magnifies only four times, whilst to the aged it may magnify ten or more times.

But, to avoid confusion in stating the power of any lens, it is desirable to fix a distance at which most persons can see, in order to measure the magnifying power from it. *Ten inches* has been thought by many the best distance to agree upon. Compared with a measure at this distance (subject to a correction which will be explained farther on), a five inch lens is said to magnify twice, a one inch lens to magnify ten times, and a tenth of an inch lens one hundred times; because these lenses enable the object to be brought in those proportions nearer to the eye. We may say nearer to the lens, for this singular circumstance arises, that it makes no difference in the power, whether the eye is near to or far from the lens; it only makes a difference in the quantity seen. If the lens, with the object still in its focus, be removed to twice the distance from the eye, the lens is seen under half the former angle, and only half the length or width of the object is seen through it; therefore, the object is not reduced, but the lens only, by its distance from the eye. If the lens is removed ten or a hundred times as far, its apparent size is reduced in that proportion; but then only one tenth, or one hundredth part, in width or height of the object is seen through it; consequently, what is seen is under the same angle, and is quite as large as when near to the eye.

To make this clear it may be differently stated. Let a frame or a ring be placed so near the eye that the whole of a church or large building can be seen through it; then let the frame or ring be moved farther from the eye, and we shall see less and less of the object through it: at twice the distance we shall see but half the height of the building, at ten times the distance one tenth of the height, and so on; because the ring or frame lessens with its distance. But what is seen through the ring or frame remains of necessity the same in size: the act of moving the frame or ring nearer to or farther from the object cannot alter its apparent dimensions, although it may limit the number of its parts. But let a lens have an object fixed in its focus, and both be moved to or from the eye, we shall see the extraordinary fact of an object not altering its size, or appearing under a different angle, when it is removed farther from or brought nearer to the eye; the lens alone alters in size according to its distance, consequently we see more or less of the object through it, precisely as we did the church through the frame or ring.

When an object is placed in the solar focus of a lens, the eye views it with the same adjustment that suits the distant horizon. An ordinary eye has adjustment for every intermediate distance between that and six inches; and the question has often been asked, what is the limit or quantity of that adjustment remaining with the eye when it looks through a lens? Let a person whose best distance of sight is six inches, take a six inch lens, and through it he can see as near as three inches, and he can also see as far as its focus, or six inches; therefore he has three inches range for his sight, and he uses every portion of the eye's adjustment, from very near to very distant, when he extends his view from the three inches to the six.

An inch lens will shorten his sight seven times, or to six-sevenths of an inch; and as he can see to its focus of one inch, he has one-seventh of an inch range. A lens the tenth of an inch will shorten his sight sixty one times : divide the tenth by sixty one, and his range is only one of those parts, or the six hundred and tenth part of an inch. The sixtieth of an inch will shorten a six-inch sight three hundred and sixty one times, and gives a range of only the twenty-one thousand six hundred and sixtieth part of an inch: hence the extreme fineness of the screw that is required for its adjustment. These ranges are of course the limits of the thickness that can be viewed without altering the adjustment.

With low powers the whole thickness of the object is frequently much within the range of sight, and therefore it does not require such nicety of adjustment; but with very high powers most persons have felt the want of a finer adjustment.

When determining the magnifying power of lenses a correction was alluded to, and by comparing the above with what is there said, it will be seen that opticians have adopted an error in measuring the power, which error lessens exactly as the range of sight lessens; this with high powers is not worth noticing, and with any power, when understood, it saves fractions in the measure.

To avoid those fractions, a lens of the same focus as the eye is supposed to magnify none, for which they say one, and a lens of half that focus is said to magnify twice. Now, a lens of the eye's focus enables us to see an object at half that distance, consequently under twice the angle, therefore it magnifies twice; a lens half the eye's focus enables us to view an object at one-third of the distance, therefore it magnifies thrice; a lens one quarter of the eye's focus magnifies five times; a tenth of the eye's focus will magnify eleven times; and so on: for as a combination of ten lenses, each equal to the eye's focus, lessens the focus exactly in proportion to the number of the lenses, if we add the eye's power to them it makes eleven; consequently they will shorten the sight to an eleventh part, which is the power.

The most refined exertions having been made by scientific men to ascertain the exact curves and combinations that would bring optical instruments to perfection, it is lamentable to see how much those labours are deteriorated in the execution, through the unwillingness of workmen to adopt any change in their practice.

In illustration of this observation, I shall endeavour to shew the defects that must and do result from the ordinary mode of polishing lenses, and then describe one that must necessarily be free from those defects, if my directions are strictly attended to.

Lenses are prepared for polishing by being ground in a grinder, or metal tool, of the requisite curve; brass is the metal generally preferred. Emery, differing in degrees of fineness, is used in succession. The coarse emery is used to grind them into figure, and the finer to keep that figure when produced, and bring it as near as possible to a state of polish: this is technically called smoothing.

Of the Cloth Polishing Tool.

The case or support of the polishing tool is made of metal, of a larger curve than the grinder above described; into this case is cemented a strong, thick piece of woollen cloth or drugget, which fills up the superabundant space in the curvature of the case, so as to become of or form the same curve as the grinding tool.

The interstices are well filled with polishing stuff, which is either *oxide of iron or oxide of tin.*

The tin is mostly used in these cloth tools. They are kept wet, and well supplied with fresh oxide and water during the time of rubbing them over the lenses, or rubbing the lenses in them. This is continued till the lenses are *sufficiently* polished,—and I would say, why not *quite* polished? or worked a little more than the requisite time, in order to secure the most perfect and brilliant polish. I before said *sufficiently polished*, because former opticians found, when making telescopes, the longer they kept polishing the lenses the worse they performed; and therefore they did not dare to obliterate all the marks or imperfections on the surface produced by grinding, for fear of losing the true figure or curvature produced by that process. Notwithstanding this circumstance is well known, opticians to this day have not given up so bad a mode of polishing, though some have considerably lessened the evil by lining their tools with a thick kind of silk, instead of cloth or drugget, as before described.

If we consider the nature of the material, we shall see how liable it must be to render the lenses bad, both in figure and surface. The cloth, it is well known, is elastic, and its interstices very unequal, those between the threads being large, those between the fibres very small, and the portions of the threads that cross over each other are, of course, so many harder prominences.

The glass, however smoothly ground, is only in a finer or more minute state of roughness, on which the elastic and unequal surface of the tool will act unequally; some of the minute hollows it will merely unite together into one, and polish the surfaces of them before the neighbouring prominences are completely reduced. Here, then, will be a polished wavy or undulating surface, which will cause a vibratory action of the tool, and which action will increase till the wavy surface of the lenses corresponds with the average inequalities of the cloth tool. Thus much for the surface only. We will next observe the effect which an elastic tool must have on the figure. The cloth being elastic, the lenses sink a little into it, which causes the tool to act more on the circumference than at the centre of each lens and give a quicker curve, as shewn in fig. 5, Plate V. Accordingly, the circumference is always found to be bad, and is cut off, or reckoned to be hid by the seat of the cell in which the lens is put for use. A portion of the lens being thus obliged to be cut off, makes the lens larger in diameter, and consequently thicker than it otherwise need be. This is fault enough; but though the very worst portion is cut off or hid, there still remains a portion of the fault graduating inwards towards the centre, which prevents the lens from bearing anything like the aperture it would do if perfectly spherical. For it is a fact, that if lenses could be worked a little flatter towards the circumference it would much improve them; but the rounding off just described is the very reverse, and makes them much worse than truly spherical lenses. Again, if a lens is polished alone, the polishing tool being elastic renders the lens liable to tilt or roll in the tool. If this takes place, the longer it is in polishing the worse will it become; for the quickness of the curve towards the edges will continually increase, giving more of the error shewn in fig. 5.

This tilting is totally prevented by polishing several lenses together in what is called a block. For this purpose they are cemented on a curved tool called a runner, the curve being concentric and parallel to the curve of the grinding-tool, but having a space between the two curves equal to the thickness of the lens or lenses to be laid upon it, that they may be equally supported. The lenses are always laid together in the most uniform manner, to fill a circular space if possible. When only three larger lenses are put together, three small ones are frequently added, as fig. 6, Plate V., to support the tool.

By thus clustering the lenses together, they may be ground and smoothed extremely perfect: and where the lenses meet each other the polishing tool will be considerably supported, so that the evil arising from its elasticity will be lessened; but towards the intervals the cloth will sink in and round those parts. Some opticians, contending with this evil, put very small lenses into the intervals, and thereby lessen the evil still farther; also, a ring of small lenses is put round a single large one to support the tool. But do what they will the fault is never totally removed.

I am fully aware that some interested persons will attempt to deny all that has been stated upon this subject, except the rounding of the extreme edges, and this they will readily allow, because they say the defective parts can be cut off.

I will therefore describe a method of rendering the fact quite visible.

Detection of Faults.

If a convex lens is put into a concave one whose curve is a very little larger, it will touch at the centre, and the extraordinary effect takes place, that the reflecting power of the two surfaces around the point of contact is lost, and there appears a small circle through which the light passes, as if it was but one glass; at a little distance around this spot coloured rings appear, and if the two lenses are correct in figure, it is evident these rings will be true circles.

Let a finished lens be taken off the block, and mark on its back the places where it was touched by the surrounding lenses. Put this into a concave lens of larger diameter, as truly worked as possible, and of a curve that ought to correspond, or be exactly the same as the convex.

It is evident, if these lenses were true, that they would fit, and produce a uniform tint; but, instead of that, coloured rings or segments will appear, either like fig. 7 or fig. 8, the indents being greatest where the tool was least supported.

Next, to ascertain whether this fault approaches the centre, put the lens into a concave of a very little larger curve; this will bring the coloured rings nearer to the centre, when, instead of their being correct circles, they will shew a tendency to be slightly indented, like fig. 9.

This I believe to be the most perfect test that can be applied to ascertain whether a lens is truly spherical. Turning one lens round in the other will shew whether the faults are divided between them, or are all in the one under trial.

These trials so far only ascertain the general figure: comparison will shew a difference in the surfaces.

Let two pair of lenses be provided, convex and concave, so as to shew the coloured rings; let them be ground and smoothed in the same tools, but let one pair be highly polished in cloth tools, the other in a composition of bees'-wax (to be hereafter described). In the cloth-worked pair the coloured rings will be a little nearer the centre, on account of the rounding off at the edges, and will not be so sharp or bright as in the wax-polished lenses. Indeed, the plain image reflected from the surface will shew a superior brightness and sharpness in the wax-polished lens, as will be hereafter shewn.

Any imperfection in the surface will also be shewn by the method used for

Detecting or searching after Veins.

Let a black patch be put on a window of such a size that its image formed by the lens under trial will just cover the pupil of the eye, then hold your eye steadily in that focus, and the lens, if quite good, will appear black all over, though it is before a bright window.* Thus situated, you can hardly keep your eye still enough to prevent its going out on one side or other of this little black spot or image, and every time the eye goes out or in, the shadow or blackness appears to glance off or on the lens. Now, in a lens placed with such nicety, if there should be any veins, that is, parts differing in refractive power, or minute air-bubbles, they will not cooperate with the rest of the lens to form an image, but will transmit the lateral light, and will be seen breaking across the otherwise uniform boundary of light and shade, which should be made to cross the lens slowly by a slight motion of the eye.

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* For experiments with lenses, a lump of bees'-wax should always be at hand, it is so convenient a mode of temporarily attaching a lens to the window, to a stick, to a stool, or the back of a chair, in any position required.

Also, if there should be any imperfections on the surface, such as scratches or minute hollows from imperfect polishing, they will be seen breaking the boundary of shadow, which is to be moved in succession to each part of the lens. Imperfect polishing, it will be found, shews a surface something like paper.

To detect a wavy surface (supposing the lens fully polished) is more difficult: it requires to be compared with a similar boundary of shadow in a wax-polished lens, when a difference in the clearness of the boundary will prove a difference to exist in the surface.

For the sake of explanation, I have mentioned a black patch, but in practice a right line, such as the margin of a window, is used when searching for veins; but for the more minute defects of surface, the most perfect and sharp margin that can be obtained should be used to form a boundary.

By these modes of examining lenses it will be found that the public are very frequently subjected to bad vision, in cases where they ought to have the most perfect, particularly in spectacles, every defect in which is injurious to sight.

In day telescopes, having at least six glasses, their twelve surfaces are liable to imperfections, both of figure and surface, which, unless carefully attended to, must occasion a great drawback on their performance.

The evils above described may be considerably lessened by smoothing to the utmost in the process of grinding, so as to leave less work for the polisher; for the less it has to do the less can it alter the good figure given by the smoothing tool.

And the imperfection is still farther lessened by using silk instead of cloth to line the tools for polishing.

Pitch Tools.

Mr. Tully cures these defects which remain from cloth tools, and obtains a perfect figure and surface, by finishing his object-glasses on pitch tools, similar to those used for speculums. For lenses, pitch is a later introduction than bees'-wax; it will not, however, do for small ones. It therefore appears nearly confined to that excellent purpose for which Mr. Tully has so judiciously adopted it.

Wax Polishing Tools.

My late uncle, Mr. Samuel Varley, adopted the use of bees'-wax for polishing lenses at least forty years ago. He rendered it sufficiently hard by mixing either fine tripoli or oxide of iron with it. The wax is melted, and the powder very uniformly stirred in. A sufficient quantity must be added to make it so hard that the nail of the finger can but just scrape or indent it, but not so much as to make the compound lose the waxy character: if it is too hard it will not yield to the pressure of the lenses, or allow them readily to bring it to their own figure, by scraping off any prominences; if it is too soft, it will yield too much to the pressure after it has come to perfect figure, and will not be so durable. But a little trial of two or three mixtures, differing in hardness, will soon teach the operator which is best. I have generally made it as hard as I could use it for very small lenses, and softer for the larger ones: that which will suit a block of two-inch lenses is soft enough for any sized block.

In Plate V. fig. 10, is the section of a polishing tool. The brass cup which holds the wax is turned spherical, similar to a grinding tool, but left rough inside, being purposely turned with a pointed tool; and it is from a quarter to half an inch larger or deeper than the required radius, to allow of that thickness of wax. It is made hot enough to let the melted mixture, when poured in, adhere to it, and the roughness gives it a better hold; when cold it is put on the lathe, from which all dirt is cleared, and the workman, with arms or sleeves free from filings or dirt of any other work, turns it out to nearly the right curve with a curved, thin, sharp tool, such as a carpenter's chisel, and then finishes it with a sharp and truly-turned gauge, made of thin steel. This gauge is made a very little smaller so as to fit quite easy in the grinding tool; because it is better to secure the contact of the tool and lenses at the outside first, and the progress of working will soon bring them to fit all over. Fig. 11 is a block of lenses suited to the polishing tool fig. 10. Fig. 12 is a section of the brass tool in which they have previously been ground.

When the grinding and polishing tools are of long radius, but within reach, they may be turned nearly right, and then finished by a tool, whose stiff handle makes it longer than the radius. A hole is made through the handle exactly at the radial distance from the cutting edge: this hole is put on a pin, which is fixed correctly in the axis of the lathe. The cutting edge of this tool can then only move in the right curve; and by slowly traversing from the centre to the circumference and back again, it will give the right curve, and finish the tools.

The cement which holds the lenses to the block must no where rise flush or level with the surface, and if any appears near it must be scraped down.

If when the workman begins to polish there is not a perfect agreement between the lenses and tool, the sharp edges of the glass will scrape off the redundances: these scrapings must be removed from between the lenses as soon as they appear, otherwise they will form lumps in the intervals, and react on the tool. So soon as the block and tool coincide, polishing goes on very pleasantly.

The finely washed polishing stuff is mixed with water, and the tool is, by means of a feather, supplied often enough to be always wet.

With these tools and cleanliness there is very little liability to scratch, for the softness of the wax cannot support any one part above another; yet it holds an equal layer quite well, and polishes quickly if we use nearly as much pressure as the materials will bear.

This due degree of pressure secures a constant fitting of the tool to the block; and by their cleaving or being held together by the pressure of the atmosphere, the block can never roll or tilt; it can only slide if due attention is paid to these directions.

This mode of polishing can never produce the faults that occur with cloth tools. The composition is soft, but perfectly inelastic; it therefore can yield a little to a prominence, but can never return; it can never spring up into the intervals, and round off the edges of the lenses; and if it is pressed or cut away by any accident, it remains in that state until the rest is cut or squeezed away so as to agree with it.

If by any impropriety the tool is put out of figure, a little care soon brings it to fit again.

Thus the complete homogeneity, softness, and yet perfect inelasticity of the material, and its surface, enables it only to work or exert its powers on prominences, and never in any hollows, be they large or ever so minute. Continuing to polish more than enough does no harm; its tendency is always to produce and keep perfect sphericity.

Many opticians use a post to polish on, and keep stepping slowly round it. I never had patience for such tedious work, but always used a lathe with the quickest motion that I could govern, and keep on the polishing stuff with. This last check allows the speed to increase exactly as the diameters decrease: I therefore used a very light horizontal, or jewelling lathe, for the very small lenses, and attached an extremely swift motion for the most minute lenses, such as the 60th or 100th of an inch. For one and two-inch lenses I used a strong lathe, and for large work a very strong vertical mandril, called a lap.

The tool is always to revolve with the lathe—the lenses never; but they are caused or allowed to revolve slowly, or change sides in the hand, and are kept constantly sliding about on the tool: the centre of the block being kept eccentric, and carried round so as to meet the motion of the lathe, keeps bringing every outside lens in succession across the centre, and secures equality of action both on every lens and on the tool likewise.

Lenses thus polished, from their perfect continuity or soundness of surface, wipe clean easier than others, and bear the largest possible aperture, because they are perfectly spherical, and a larger portion of rays pass through the lens to form an image, or give vision, and there are none injured to confuse the perfect rays; consequently, vision through these lenses may be as perfect as their substance and combination of curves will allow.

Polishing Stuff.

The difficulty of procuring oxide of iron free from grit or scratching particles, has caused many opticians to prepare it for themselves. A solution of the sulphate of iron is made, and then precipitated by an alkali; the precipitate is put in a covered crucible, and heated till it becomes of a red colour. This oxide, whether made or purchased, is always to be washed by stirring it up in a deep vessel of water, and pouring off as soon as we judge the coarser particles have subsided.

Cements.

The ordinary sized lenses are cemented on to the tools with a composition of one pound of dry and finely powdered whiting, one pound of powdered resin, and one ounce of bees'-wax; to lessen the brittleness, they should be well mixed together while hot, and the air-bubbles allowed to escape. But the strongest cement known is made with shell-lac and finely pulverised pumice-stone, mixed while hot. My late uncle used this for his watch jewellery; and for the small lenses shell-lac alone is a good cement, and stronger than most others; but its strength is still farther increased by the addition of pumice-stone.

Method of making Small Lenses.

For the larger lenses plate glass of a suitable thickness, and very free from colour, is cut into squares, avoiding those pieces which have veins or minute air-bubbles; the corners are snipped off with tongs, pincers, or pliers, till they are nearly round and of a suitable diameter. These have a cone of cement stuck at the back to serve as a handle, or they may be stuck with cement on the end of a stick; they are then ground singly, sometimes at the grindstone, to make them approach the figure, and then brought nearer, by grinding singly with coarse emery in a tool similar to that which is to finish them, like fig. 12. They are next, with a cone of cement sticking to their back, laid in the grinding tool, suppose fig. 12, and arranged equally in proper order; the runner, fig. 11, is made warm enough to soften the cement; it is then pressed on without deranging the lenses, till it just or nearly touches their backs, and it is kept central till cold. This sticks them on in the manner shewn in fig. 11. They are then ground in the tool, fig. 12, till every part touches the tool and agrees to one sphere; and, lastly, are smoothed and polished, as before described. Lenses are much the best that are worked in a block, because there can be no rolling or tilting, and in very small blocks we can fill nearly a hemisphere, which is sure to work well. The smaller the lenses are the larger is the portion of a sphere they must occupy, to secure their working truly without rolling or tilting in the tool. Therefore, when the size will admit, small lenses should be worked at least three in a block, because they may then be as thin and small as the intended aperture will allow. I have used blocks as small as the tenth of an inch, making three hollows in the runner to take better hold of the lenses; but of that size generally, and always below it, they are worked singly; and though thin lenses are best, these are obliged to be much larger, and therefore thicker than requisite for use, that they may occupy a sufficient portion of a sphere to secure a true figure.

For the tenth of an inch, and all below, I first make spherules, by taking narrow slips of the clearest plate-glass (such as will not produce air-bubbles while melting), and drawing them out by a lamp and blow-pipe into threads about half as thick as the intended spherules. The ends of these threads are melted before the blow-pipe, and kept revolving that they may not drop aside, until globules of the right size are formed, like fig. 13; these are broken off and stuck, with the shell-lac and pumice-stone cement, in tools like fig. 14 (called a runner), the stalk being placed upwards; they are then reduced at the grindstone to half a sphere, and taken out to be cemented with their rough sides on smaller chucks or runners, like fig. 15; after which they are ground in the revolving tool, fig. 16, and polished as in fig. 17: these being nearly half a sphere, are ground and polished with ease and truth of figure; the bright sides are then carefully cemented on still smaller runners, like fig. 18, and the flatted sides ground convex, till they are as small as can safely be worked without loss of figure. It is requisite to take the broadest possible hold of the lens while grinding or polishing, that it may not come off before it is finished; therefore I always bring it in contact with the rim of the runner to give it the best support, but the runner must never be as big as the lens, lest it should come in contact with the tools and spoil them; and when the polished side is on, the hollow in the runner must be a little larger than the intended aperture, and deeper than the lens, to prevent injury; for the cement, while cooling, sometimes draws the lens so forcibly against the runner as to mark it all round, bruising the glass in a circle like a scratch: for this reason I make the hollow only a little deeper than the lens, so as to hold but just enough cement; the force from contraction lessening as the thickness of the cement is decreased.

When plano-convex lenses are to be made, I first polish a number of hemispheres, like fig. 15, and then cement them on a flat runner like fig. 19. Fig. 20 is a section of it: the hollows in this runner are very equally distributed; they are less than the diameter of the lenses, but larger than the intended aperture, and a little deeper than the curve of the lenses. They are neatly filled with cement, and the hemispheres placed on them while hot, with their flat sides upwards, and each individually pressed down into close contact with the margins: they are then ground on a flat tool (always using the finest emery that will answer the purpose) till reduced to a proper thickness; then smoothed either on the same tool, or on one kept for the purpose, with the finest washed emery; and, lastly, polished on the flat tool, fig. 21, which is an edge view, *f* and *g* being its wax surface. I always examine these small lenses as they proceed with different powers, and polish them till their surfaces become invisible through a lens the twentieth of an inch focus; making use of the greatest velocity that can be kept supplied with wet emery or wet polishing stuff.

When completely polished, the runner is made warm enough to loosen the lenses, they are then taken off and put on paper to prevent scratching, in a small vessel of spirits of wine: this is made hot enough to dissolve the cement, and when they look clear they are taken out one by one, and wiped on clean leather, that being the best substance, as it is not liable to scratch. The tweezers for taking them out are brass (because, if clean, it does not readily scratch glass); they are made rough inside to prevent the lens slipping, and I never let these or any thing hard touch the polished surface, but I take up the lenses by their diameter. The resin cement is removed in a similar manner by spirits of turpentine.

Convex or concave tools are so much easier to keep in true figure than flat ones, that I prefer using a long radius instead of a flat one whenever it will suit, and on that account I again prefer Herschel's doublets, their longer radii being a convex and a concave.

Figs. 22 and 23 are a side and front view of one of the small steel gauges. It is turned nearly to the right figure, and then hardened and tempered, or let down to a blue colour; it is then put in the lathe, and turned very thin and true to the right diameter: the stalk or axis behind is turned as thin or small as the strength will bear, to give room for the gauge to dip into the tools. As the grinding and polishing tools ought never to be a whole hemisphere, the half stalk less than a semi-diameter of the gauge is enough.

Two of these gauges are made. One, to be kept and occasionally compared with the tools in use, to know whether the work is so properly managed as constantly to preserve the same curve, for that is very essential, and more particularly in the smallest doublets of Herschel's, to keep very accurately the true proportions of the different curves; and preserving the figure is one proof that the lenses have been rightly worked, and are likely to turn out perfect. On the contrary, if the tools wear to a different curve, it is a proof of indifferent management, and the lenses are likely to be inferior.

The second gauge serves as a turning tool, to form the polisher, and in some cases to finish the grinding tool. The most minute gauges I always leave very nearly hard, only tempering them to a straw colour, to secure a little toughness, and turn them with sapphire, ruby, or diamond turning tools.

Glass spherules have frequently been used as magnifiers. Figs. 24 and 25 shew an easy mode of mounting them for use, in the absence of better means. A slip of thin brass, called latten, is first folded along *h h*, and then pierced with two or three holes of different sizes, to suit different spherules, as fig. 25—a sharp drill or a pen-knife point will do it; the fold is then a little opened, to scrape off the burr; the spherules are then laid in their places, with a little of the stalk remaining on, to secure that bad part keeping aside; the fold is again closed on them, and the narrow side *i i* folded over the edge of the first fold to keep it down, and they are then ready for use. Fig. 25 is an end view, to shew the curvature given to the bottom, by which the spherules better approach the object. If a small lump of wax is stuck on a slip of glass, near to an object laid on it for examination, this mounting may be squeezed on to the wax, and the spherule fixed in focus thereby.

I shall now state some of the advantages which result from using a microscope of this construction, and add a few sketches of animalculæ observed with it; and, as circulation has been discovered to exist in a plant called *chara vulgaris,* I subjoin the result of many additional observations, which my microscope has enabled me to make, accompanied with correct drawings of various parts and stages of that most highly interesting plant, as I am not aware that any thing of the kind is at present before the public.

Ten inches being the distance of an object from our eye, when we compared it with the magnified view, I have purposely placed the eye-piece ten inches above the table, and the base being removed to one side, gives room for a common rule to be laid under the microscope, and, with both eyes open, one of them can see the object and the other the rule, apparently together,—the object may therefore be measured; then dividing its measure by the known power of the lens gives the real size. A lens with a twentieth of an inch focus magnifies two hundred times, compared with a distance of ten inches; therefore, if an object viewed through it measures one inch, its real size is only the two hundredth part of an inch. This mode of measuring applies particularly to living objects, and to any already mounted, or that you cannot bring close enough to a finely divided slip of glass to see them both together; for it makes it quite immaterial how the objects are mounted.

The refractive power of minute vegetable globules may also be measured, by first accurately measuring their magnified diameter at ten inches below the microscope, then adjust the lens till the globule gives an image of an object of known magnitude, placed before the light and at the same distance of ten inches from the globule; measure this image, and its proportion to the object will be as the globule's focus is to that of the lens. Suppose the lens be a sixtieth, and the image is reduced to half, then the globule's focus is the hundred and twentieth part of an inch. A glass spherule the sixtieth of an inch in diameter would give the same sized image. Now, if the vegetable globule is the eightieth of an inch in diameter, then its refractive power is only as three to four of glass; but should its measure be the fiftieth, its refractive power would be one-fifth more than glass.

Also, if the globule be in water, and it gives an image as big as a globule of water of its own size would give, (which is known from the proportion of water to glass,) then the refractive power will be twice that of water; and so for any other proportion; for to give any image when in water, its refractive power must be more than that of water.

If paper is laid under the microscope, it and a pencil will be seen with one eye, and the object with the other; and by a little care it may be traced. The object can always be so adjusted as to appear of exactly the same distance as the paper, and then the same vision or state of the eyes suits both.

If the microscope is clamped so as to overhang a table, or a much higher stand, a board may be sloped on the floor in a convenient position, and the microscope inclined so as to agree with or have its stem perpendicular to the board, then a very large drawing may be made or traced from the object, by putting the pencil at the end of a long reed-stick, and steadying the upper end under the arm.

As a proof of the accuracy with which an object may be either copied or traced, in Plate V. fig. 51, is shewn a petal of the *anagallis arvensis* of the real size, with a tracing magnified twenty-one times, fig. 52. This is a reduction of a much larger one, of twenty-one inches in length, being magnified one hundred and five times. I traced it in July 1830, for R. H. Solly, Esq. The petal is barely one-fifth of an inch; yet all the veins, with their ramifications, their joints, and terminations, are distinctly and accurately shewn in the drawing, and all correctly laid down in their respective places. The veins of this petal consist entirely of spiral vessels, with peculiar joints and terminations: *n o p* and *q* around the petal are portions of them, magnified three hundred times; the same letters on the petal shew the places to which they belong. *r* is a vessel dissected from another petal, and pulled out to shew its spiral continuity. The circumference of the petal is beautifully decorated with projecting cells, on each of which two more oval cells are mounted, the upper one being largest: they are perfectly transparent, and filled with a crimson coloured fluid. The rest of the petal is made up of long cells, the walls or partitions of which are permanent, even when the petal is rendered transparent; but the upper and under skins consist of regular lines of smaller cells, very long at the foot, where they agree with the inner cells, but shortening as they advance, till they are no longer than they are wide, and resemble closely strung beads. The bottom of the petal is purple, the next part crimson, and the remainder scarlet.

The petal is rendered transparent and colourless by immersion in hot water, or more slowly if immersed in spirits of wine. The immersion appears to render it transparent either by breaking the partitions of the small cells, or dissolving the matter within them so as to reduce its refractive power. As the petal becomes transparent the small cells disappear, and cause the partitions of the long inner cells to appear zig-zag and sometimes studded: but these partitions remain clear lines at the foot, where the outer and inner cells coincide.

The bright and very small pencil of light closed round with total darkness, has enabled me to see much better the details of plants and animals.

The trumpet-shaped animalculæ, Plate IV. fig. 8, one being closed and two seen open, have a complete fringe of small fibres, which appear to be revolving quickly; but the muscles which actuate them are also seen, and they are stationary, lying or radiating across a narrow band;

and the currents produced, shewn by doted lines, meet the aperture of the trumpet much quicker than the apparent motion; which proves it not to be the real one, but the result of an invisibly quicker motion.

This light also renders beautifully visible the very long muscle or muscles extending through the stem and branches of the bell-polypus, with the wrinkles occasioned by its action. The principal stem is shewn in Plate V. fig. 27, magnified 300 times, being viewed through a lens of the thirtieth of an inch focus: it is colourless and transparent. The origin of the muscle appears to be about *a*, a little above the root or foot; and each branch-muscle appears to have a separate origin at the commencement of the branch. The contractions are so quick as to be a perfect vanishing; its coils are numerous like a wire bell-spring; they however uncoil slow enough to be seen distinctly.

Fig. 28 is the same, less magnified, in order to shew the whole. The bells sometimes amount to hundreds. *b* is one of some that became nearly quiet, and seemed to have lost the bell shape; *c c* represents a few of numerous smaller animals, or bells, probably young ones. Fig. 29 is a single bell with a long string, containing a muscle throughout, capable of coiling in any separate part or all together: the coils pull out singly in succession. Fig. 30 is a kind with straight stem and branches, containing no muscle, and appearing motionless: the contractions were only in the conical bells, as shewn by the wrinkles. The bells have small fibres, whose motion produces currents similar to the wheel or the trumpet animalculæ. These varieties were observed near each other in the same drop of water, attached to a stem of duckweed. The branch *d*, fig. 30, had a similar head to *b*, fig. 28 ; but by the manner in which this branch is attached to the rest, it appears not to have been originally one of that family.

A group of minute green globules, which appears like a planetary cluster or system, always revolving as they move, when placed over the dark chamber are seen to be included in a very thin and perfectly transparent globular film, apparently as clear and smooth as glass ; some samples are elongated, just enough to shew that one end always keeps foremost while moving, the longer diameter being the axis on which the globe revolves. It is about the two-hundredth of an inch in diameter, and contains from twenty-seven to thirty of the green globules : these are close together when young, but in the old they are quite separate, and begin moving among themselves some time before their birth ; and when the globe breaks up these all swim about, revolving, and begin to shew internal clusters.

Another curious family is shewn in fig. 39, Plate IV. It consists of green globules similar to the above, but always arranged in a flat square, wanting the four corner globules, and the number of globules thus arranged or connected is always sixteen, the four middle ones being rather the largest, and they are generally the first that separate. I have seen one of these swim out from a complete group or family, and begin to perform a kind of oscillation, when it soon increased in size, and then developed the same divisions as the parent group, being minus the four corners. The parent group swam about for some time, and then gradually broke up into separate ones. These mostly revolve or vibrate a little way round and back, and they then swim one side foremost, that evidently being the front or head of the creature; and from its meeting the water as a kite does the wind, appears to be the cause of the oscillatory motion. These figures are magnified two hundred times, being an edge and a front view. The width of the group was therefore the eight-hundredth of an inch, and the young, when just separated, only the three-thousandth of an inch.

The small plant *chara vulgaris,* known to botanists as growing entirely under water, has, during the great improvements latterly made in microscopes, excited much interest from the discovery of a circulation within it. This important fact rendering it very desirable to have a correct microscopic description, I hope the following account of that very peculiar plant may prove acceptable to the public.

In the month of May last I was made acquainted with the *chara* by R. H. Solly, Esq., who favoured me with a portion, stating that the circulation could be seen in it with a good microscope. This I examined, and preserved it in a growing state, and soon saw the beautiful phenomenon of a circulation in various parts, and also in the new and very fine roots which it sent out from time to time. During the summer Professor Burnett favoured me with a plentiful supply, since which I have kept it growing in glass jars and vials; and now in December have got several portions of the plant, and a considerable stock of seedlings, many so far advanced as probably to need only suitable weather to begin shewing flowers and seeds.

Water-snails and different kinds of larvæ have proved very destructive to the *chara* in the large jars. I was therefore obliged either to remove them, or, what was easier, to take out all the *chara* that was free, and place it in fresh water, and strive to guard it from those flies or gnats which lay their eggs in water.

In describing the *chara,* I will begin with such a portion as we are likely to find in its native place.

Plate V. fig. 31, represents the upper end of a length of *chara,* of its real size. These are found very numerous, and entangled together, growing from the muddy bottom of water, two or three feet deep, where I obtained it. *a a* is the stem, sometimes as short between the knots as here shewn, and sometimes as long as five inches. Nine similar and regular arms *b b* grow out on the top of and with each length; from the midst of these grow out the second length, with its nine arms at top closed like fingers, and, as they open, a third length, and so on, keep growing out. From any of the knots, branches *c c* are liable to grow out: they are in every respect like the first stem *a a;* but whenever a knot sends out a branch, it also sends out very fine and perfectly transparent roots *d d.* The arms *b b* have four or five joints, from which the flowers and fruit grow.

Fig. 32 is a magnified view of one length of the stem between two knots. These stems are hollow tubes, which, in the most healthy state of the plant, are covered for their whole length with about eighteen smaller tubes. These outer tubes are frequently broken away, as shewn in the figure; and, in taking a quantity from its native place, many lengths are found entirely deprived of their outer tubes, and uncovered, and the small arms *b* either decaying or removed, leaving only the knots. These lengths, if left very quiet in water, will send out small branches from the knots, as at *c*; but in this case the first length is a naked tube, very transparent; and from the same knot perfectly transparent roots *d* are sent out : they are small tubes. In this state the plant is an excellent microscopic object. The circulation to and fro is visible in the largest tube or stem : it is beautifully visible in the young naked branches, and, with a higher power, most perfectly visible in the fine roots; for they are quite as clear, colourless, and bright as glass tubes. Under favourable circumstances, the circulation may be seen in the large tubes with a quarter of an inch lens, but the tenth of an inch shews it quite well: for the roots and the small tubes the twentieth of an inch is better. All except the roots are studded or covered with minute cells, as shewn in the short bit of stem, fig. 33, and are of a good green colour.

The small tubes *e e* which cover the stem *a a*, fig. 32, always wrap spirally round it. They sometimes are continuous tubes the whole length, from knot to knot, but sometimes they are jointed here and there, as shewn between *f* and *f*; and some lengths are intercepted with numerous joints. These short lengths of small tube have a complete circulation up and down between each joint, and when they separate from the main stem, as at *e e e*, near the upper part of fig. 32, they part at these joints and remain whole, the circulation going on as shewn by the arrows. Though the cause of their parting appears to be owing to an injury done to some of the intermediate or lower lengths, in some cases these outer tubes become too long, by growing faster than the inner part or tube, and peel off on that account, without being disjointed. I have also had some where the outer tubes appeared stationary, while the large inner tube increased in length, and thrust itself out from the small tubes to bend like a bow, the small tubes appearing to be the strings that kept it bent.

These accidents are very favourable for observing the different circulations.

At the bottom of fig. 32, one of the nine arms *b b g* is shewn at full length. In its native place, these arms are mostly covered for their whole length with about nine small tubes, sections of which are seen at *b b*, top of fig. 32; and these arms bear the flowers and fruit at each joint. *h* is supposed to be the male, and *i* the female or fruit-bearing portion of the fructification.

I have many samples growing in-doors in which these arms are quite naked, similar to the upper part *g* of this arm: they then bear no fruit. The outer tubes appear essential for that purpose; for to whatever joint the outer tubes extend, so far flowers and fruit are likely to appear. *j j* are tubes, fingers, or sprouts, growing from the same joints. Around the knots, as at *k k*, and close under the arms *b*, there are eighteen pairs of small cells, two pairs under each arm; and occasionally there are short cells *l l* along the main stem, which grow out from between the surrounding tubes: they appear always to hang downwards, and are in some cases very numerous.

Fig. 34 is a still larger view of one of the male flowers or globules: the outer portion is colourless and transparent, the inner globule is a reddish orange colour, and appears situated like a yolk in the white of an egg.

The peculiar markings on the coloured surface shew the petals, the corolla, or whatever else they may be called; the colour, in extremely minute globules, is in them: they form a globular envelope. When the globule ripens these scales fall off: one is shewn separate in fig. 35: the inner portion of the globule then expands into an open mass of filaments, which also fall away. The contour of these, when viewed through a lens the sixtieth of an inch, is something like that of a watch-chain, having globules rather larger than the filament at intervals: a part of such a filament is shewn at fig. 36. Fig. 37 the seed in its green covering, as it appears on the plant before it is perfectly ripe. Fig. 38 the seed in its shell without the green covering. Fig. 39 the seed taken out of the shell. Fig. 40 sections of the seed-skin, the shell, and the green tubular envelope. Fig. 41 is an inside view of the bottom portion of skin, such as fig. 39. Fig. 42 is a top view of the shell fig. 38. On comparing the sections with the other three figures, it will be seen that the skin has thin spiral ridges around it, and that the shell has internal recesses to fit on them, and external channels to receive the surrounding tubes. The end-view, fig. 42, shews five channels; and as there are twelve in length, they make a five-threaded spiral, each of which takes two and a half turns around the seed.

The five green outside tubes, fig. 37, lie in the channels, and have a complete circulation from bottom to top and back again, in each tube. The five neat little knobs at top are separate cells, and have a slower motion in them. The whole of the seed looks green at first, the tubes being transparent, but as it ripens the inside appears darker, the green tubes begin to fade away, and the refuse clogs the seed; but when cleared off, the shell is seen like figs. 38 and 42. The shell is quite brittle, something like egg-shell, it being white and semi-transparent: when broken off it shews the kernel or seed with a very dark, shining, chestnut-coloured skin, flexible and tough enough to bear squeezing out of shape. To examine the seed and its contents, I took the seed out of water, and when dry cracked off the shell. I laid it on a slip of glass, under the microscope, and placed a thin slip of glass above it; I made this slip touch the other at one end first, then carefully lowered the other end till it pressed the seed enough to crack the shell, with no farther violence; I then, with two needle-points, removed the fragments of shell, and, with the needles, tore open the skin to let out the contents with the least injury. On perceiving a similarity between these contents and wheat flour, I laid some flour on the same glass, side by side, so as to slide one or other alternately into the field of view, and their similarity became more apparent: when dry it was white, but more brilliant than flour.

The *chara* living entirely under water, its meal was, as might be expected, moist, and its brilliancy made it appear like minute glass globules, adhering together with weak gum-water. Some of these globules were rather larger than any in the wheat-flour, and some rather smaller, or quite as small. In flour, with less difference between the largest and smallest, there is a greater number of sizes, which, I think, is one of the causes why flour looks so white. In the *chara*, the fewer varieties, and therefore greater difference between the particles that lie together, and their moisture, gives them a glassy look; but whether wet or dry, these spherules make a good object-glass with the magnifier, so as to form a reducing telescope, and shew a very good image of the hand held about two feet from it. The flour globules do the same, but less perfectly. Thus the likeness is so far established: probably, flour fresh taken out of the wheat may appear still more like.

These seeds, when swelling to germinate, sometimes only crack the shell and throw off some of the pieces. They are frequently seen attached to the parent plant a long while after they have cast their shells; and they sometimes begin growing before they quit that place, though the greater number of seeds are found to grow at the bottom of the vessel.

Fig. 43 shews a very young seedling, magnified about sixty times. It is a correct portrait of one under the microscope. When the young plant first protrudes, it opens the five segments at the summit of the seed-skin; they part at the ridges, the rudiments of the stem and sprouts come out together and expand *a a* the main stem. This first length is always a plain or single tube; *m* the top of the root portion—some of the roots *n n* grow from it; the rest of the roots *o o o p* grow from the very bottom of it, within the seed, and none from the intermediate part. The number of roots varies, from a few to sixteen, or more: these roots have grown upwards, to come out of the same opening as the plant, and then turn downwards. *p p* is a principal root, it being larger than the rest, and throwing out branches the size of the smallest roots, as at *q*, and then again at a second and third distance.

At the top of the stem *a a* are five segments, and a sixth longer one above. They are the rudiments of the first set of sprouts or fingers. These are shewn in a more mature state, but less magnified, in fig. 44, at *r r r*. These sprouts are always irregular, one being much longer than the rest. The second length grows up from the midst of these, covered with the smaller tubes, and with nine nearly equal sprouts, just like the branch *c*, at top of fig. 32; from this, all the rest of the plant is a mere repetition of the same features at each length. Therefore the first irregular and always naked sprouts *r r* hold a similar place to the first leaves of other plants. If any damage occurs to the stem *a a* of the seedling, fig. 43, another stem will grow out from *m*, but not below it; and out of some hundreds, I have never seen two stems rise from the same seed, except in this manner, the first having been injured. The semi-transparency of the seed-skin shews that its contents have been absorbed, thus rendering the general contour of the root visible within it. The skin frequently comes away whole, and so clean as to have a horny transparency, though originally it was a very dark brown.

I have now described the plant, not beginning from the seed, but from such a portion as we are liable to find in its native place, and traced it through the bearing of seeds to their growth, into such a portion as I commenced with. I will now describe the circulation, beginning from the seed.

As soon as the young plant has protruded from the seed, and grown a few times longer than its width, it shews all the parts (but less developed) of fig. 43, and circulation becomes visible in the stem *a a*; and in the thicker portion, between the upper and lower roots, arrows are placed to shew the direction of the ascending and descending currents. The portion between the roots may be considered as one whole cell, the fluid rising up one side, then across and down the other, then across and up again. If the fluid had been pure and limpid, it would have been difficult to discover it; but, fortunately, it is always crowded with various-sized particles, mostly spherical, some clustered together, and here and there a larger mass, so that the fluid appears sluggish, as if from being of a gummy nature. It is frequently like a dilution of the contents of the seed: the irregular lines, dots, or masses within the lower portion, and the stem *a a*, shew the appearance of the matter which circulates. The stem *a a*, from root to top, may also be considered one whole cell, the fluid going spirally up one half and spirally down the other half, and across the top and bottom. I have fixed my eye on a particular mass, and followed it up and down several times, with but little change in its size and form. The inner portion of these tubes or stems is filled with fluid, without any visible density or motion. Fig. 45 is a section of a portion of stem: if the side *s* contains the ascending current, *t* will contain the descending current. The inner skin *s t* is extremely thin and flexible, and is rendered visible by wounding the stem; it will then shew itself a little wrinkled as the contents run out. The whole space *v* contains the apparently inactive fluid: it appears no denser than the water in which the plant is immersed.

Each segment at top of fig. 43 has it own separate circulation in the direction of the arrows: the irregular lines within shew the inner boundary of the fluid. The same segments have become, in fig. 44, the elongated sprouts *r r r*, having joints which divide each into three cells, every one having its own separate circulation up and down, as shewn by the arrows which accompany the longest sprout.

The section, fig. 45, serves not only for the stem, but for these sprouts; and every other part of the plant, even the roots, have the same section. *u u* the two margins of the ascending and descending cells, or where the inner skin is united, and becomes one with the outer tube: these portions of the tube are paler and more transparent, and are shewn in fig. 44, as paler lines passing in a slow spiral around the stem *a a*: the arrows shew the passage of the ascending and descending currents between these boundaries. The arrows and internal markings also shew the spiral currents in the roots: in *p* it is a continuous current to and fro between the plant and the knot of branching roots *q*, each of which is a separate cell, having circulation to and fro, and would become as long as the other roots. The ends of all the roots are liable to be filled with a quantity of the thickening portion of the circulating fluid, as shewn at *w* and *w*, the currents crossing over at the top of this portion; and when any of the largest masses touch here, they are so impeded that the smallest particles may be seen to overtake and pass them. The density of this mass is sufficient to make the end appear like a solid glass rod: the contrast at once proves the hollowness of the other portions, for they appear like glass tubes.

The roots of fig. 43 are broken off, and the length of *p* to the branches *q* is contracted: the whole length of the roots is from fifteen to twenty inches when continued in proportion to this figure.

One remarkable circumstance in this plant is its extreme simplicity; for, excepting that the surface is studded with one layer of minute cells, and the knots are clusters of larger cells similar to the tubes, all the rest of the plant is composed of tubes differing in length, in every one of which is a separate and distinct circulation.

The next remarkable circumstance is the universal spiral character, for the outer tubes wrap spirally around the inner ones. The circulation also makes spiral turns within the tubes, and the outside texture, of extremely minute cells, follows the same spiral direction.

These spirals are all to the right, as a right threaded screw; but, on the contrary, the tubes of the seed wrap spirally round to the left.

Having thus far described the plant, I have now to add that I have made an important discovery in the *chara*, that will form a separate communication to the public.

I shall conclude with describing a little microscopic apparatus, particularly convenient for examining the *chara* as it grows in a vial, without disturbing it, and then state the mode of preserving minute vegetable dissections.

Having *chara* growing in various-sized vials, with seeds and seedlings in different stages, I could not disentangle or remove them without great injury to their own roots and to those around, and therefore such as were taken out were liable to die soon after their examination.

I contrived to view them without removal, by suspending a narrow bent slip of glass (rounded at its edges to prevent injury) within a vial, fig. 46, either by string or the bent tin *x*, which formed a hook and clipped hold of the slip; a piece of lead, a bent nail, or any thing that will serve for a weight, *y*, was stuck in the clip; this pressed the slip of glass sufficiently against the side ; the *chara* being between, will grow to right and left close to the vial. This answers so well that I can use the tenth of an inch lens to view the *chara*, and in some places the twentieth. I did not let the slip touch the bottom, because that was crowded with young *chara*, but when there is room, a slip bent like *z z* will lean against the *chara* and keep it to the side: a lens l being held to the vial it may be easily viewed. Having thus brought the object within view, it was frequently rendered very pale and indistinct from the cylindrical refraction of the vial, and from the light reflected on it from the concave inside of the vial; I therefore surrounded the vial with a blackened clip 2 2, fig. 47, having a hole 3 in its middle: it is made of thin brass tube lined with black cloth. This alone would not do, so I added the dark chamber 4, figs. 48, 49, and 50, to the clip, to obstruct all but a straight pencil of light which passes through its two apertures 5 3, and across the vial to the object. The socket 6 receives the pin of an arm 7, suited to hold the magnifier 1. Thus furnished, the vial may stand on a stool on the table, and a light placed near the aperture 5, the lens 1 being adjusted to distinct vision, the object will be seen quite as well as on the microscope stage, with this advantage, that it is always ready for viewing. The vial may be twisted round and slid up or down in the clip to bring any part of its surface in view; therefore this contrivance serves for any object or animalculæ that adhere to the vial, or that glide along its surface.

To adapt it for receiving the sun's light through the dark chamber, or to incline it so as to receive the sky-light, a socket 8, with a binding screw 9, is fixed behind; by this it may be fixed on the horizontal arm of any suitable stand. The vial should not be left in the clip, because darkness slackens the *chara's* growth. Always hold the vial firm on the table whilst sliding the clip on or off, because shaking the vial kills the fine roots, by breaking or bending them.

Method of preserving minute Vegetable Dissections.

A suitable slip of clear glass is fitted with a thin slip of clear talc, a little smaller than the glass; a small bladder of white lead, such as are prepared for artists, is punctured with a tack, the paint is squeezed out on the glass, so as to make a bank or ridge all round and rather less than the talc : this ridge is to be made quite sound, and spread evenly with a pallet knife, taking care to leave it thicker than requisite: the cell thus formed is partially filled with spirits of wine; the dissection, taken from spirits in which it was soaking, is laid in the middle of this fresh portion; the slip of talc is bent like a bow that it may be pressed on the paint at one end first, and be progressively lowered to touch the paint nearly all along the cell, but not quite; the last end must be kept up till the first end is pressed farther to touch the spirits, and continue the pressure gradually along, till the last air-bubble goes out at the open corner ; then, without letting the spirits follow, finally close the talc on the paint, and wipe the margin clean. This may be left for a day, and then a slip of paper the size of the glass, in which a neat aperture is cut rather larger than the object, is to be pasted on over the talc : this preserves the edges of the talc from splitting, and keeps the surface from being scratched, and on it may be written the name of the preparation. The most minute dissections will not bear moving from the slip of glass on which they are made ; therefore, a margin of paint is laid around them as soon as they are ready, and the spirits carefully put in and the talc closed over, as above.

Caution.

To secure a durable transparency, the paint must be as stiff as can be used to prevent any of it mixing with the spirit, at the time of securing the air-tightness of the talc. Old paint serves best: it having become rather glutinous, is less liable to soften and mix with the spirit.

If newly prepared, or, rather, if liquid paint is used, the spirit is liable to wash up some of the paint and some of the oil, in extremely minute globules, which will dim the preparation, and make it appear like glass that is breathed on. If the spirit is diluted with water as much as its preserving powers will bear, its action on the paint will be almost destroyed, and the preparation remain bright.

Having mentioned the public-spirited patronage given to microscopic improvements by Dr. Goring, it is but just to add the name of R. H. Solly, Esq., whose liberal patronage in the same cause has mainly fostered these microscopic communications to the Society, and brought them much more fully before the public than otherwise they would have been.

I am, &c. &c.

A. Aikin, Esq. CORNELIUS VARLEY.
Secretary, &c. &c.

SUPPLEMENT.

Letter from R. H. Solly, Esq. on certain Parts of Vegetable Structure.

SIR,

HAVING acceded to Mr. Cornelius Varley's request to have a botanical drawing he made for me engraved, for the purpose of illustrating his paper on the microscope, it may, perhaps, not be uninteresting to the Society if I add some observations to the description of the drawing already given by Mr. Varley in his communication.